Landscape pattern and fragmentation of natural secondary forests in the eastern mountainous region, northeast China: A case study of Mao'ershan forests in Heilongjiang Province

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Abstract: Mao'ershan region is a representative natural secondary forested region in the eastern mountainous region, northeast of China.. Under the support of ARC/INFO and GIS technology, the landscape shape and fragment indices of Mao'ershan experimental plantation were studied by combining the forest type map (1:10000), which was drawn from the aerial photographs (1999), field investigation (1999) and soil utilized map (1:10000). The results showed that the shape index and shape fragment index of natural landscape were higher than those of artificial landscapes and landscape patch fragment index depended on the number of patches. The natural forest had complex shape, suffering little jamming, and its shape index was higher than that of artificial forest. The manual controlled landscape (e.g. nursery, cropland and cutting blank) had regular shape, and its shape index was smaller. The fragment index of patches in natural forest was higher than that of artificial forest. The soft broad-leaved had the highest fragment index of patch amount.

Keywords: Landscape; Patch; Shape index; Fragment index
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Introduction

Landscape is formed by the spatial mosaic of patches, which are different in type, shape or size. Under the background of the matrix, landscape is directly or indirectly linked by corridors. Landscape pattern is not only a spatial distribution of patches in certain temporal scale, but also an expression of geographic process in certain temporal and spatial scale (Wang *et al.* 1996). It is a product of long-term effects of biotic progresses in landscape region. At the same time, the landscape pattern has direct and indirect effects on the biotic progress. To be brief, the landscape pattern is the product of landscape progress, while the different landscape pattern affects the landscape progress intensively (Wiens 1994). Thus realizing the characters of regional landscape could provide the scientific warranty for the rational management and utilization of regional resources (Yue *et al.* 1997). Landscape fragmentation is an important parameter in describing landscape pattern. It is a process, which changes from simple to complex under natural or human disturbance; namely, landscape changes from a single successive homogeneity to a complex un-successive heterogeneity mosaic (Bu *et al* 1999). Fragmentation is not only influence the landscape structure, function and ecological process; but reflects the human activity influence on landscape. The landscape fragmentation could form the different layout, which has different influence on the locally ecological progress and even produce negative influences on many species and ecological progress. The smaller the fragmentized patch is, the higher the degraded degrees of population density and the species extinct rate are. The landscape fragmentation means the isolation in geography, and it is one of the important causes in decreasing the species diversity. There are close relationship between the jamming intensity and the landscape fragmentation. With the increasing of jamming intensity, the fragmental degree of landscape intensified, while the fragmental degree of shape was weakened (Wang *et al.* 1997). The length and intensity of human activities have distinct embodiment in the landscape fragmentation (Chen *et al.* 1996). Due to the human being's tendency of directional selection, many landscape types have degraded or disappeared. At the same time, intact landscape was divided into many different patches, and then the landscape was fragmentized. Finally, the concomitance of landscape fragmentation and the increasing advantage have been formed. In a word, landscape fragmentation is the concurrent results of human and natural interferer. The vegetative regeneration could lighten the fragmentation, and some species rehabilitation could reduce the effect on fragmentation (Nilsson *et al.* 1995).

Mao'ershan region is a representative natural secondary forested region in the eastern mountainous region, northeast of China. Based on the research of landscape pattern and fragmentation, we seek the relationship between the landscape structure of natural secondary forest and naturally ecological progress and social economy in order to utilize the land resource rationally, conserve the biodiversity, and to optimize the layout of landscape ecology. The results also provided the basis for the management of natural secondary forest and the restoration of primary broad-leaved and Korean pine forest,

Study areas

The study was conducted at the Mao'ershan Experimental Forest Farm of Northeast Forestry University, which was located between latitude 45°20'–45°25'N and longitude 127°30'–127°34' E, 108 km far away from Harbin, with an average altitude of 300 m. Mao'ershan forestes belong to Changbai Mountain vegetation. Forest type is second forest succeeded

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from the zonal cimax xommunity---broad-leaved/Korean pine forest due to human disturbance. The main tree species are *Quercus mongolica, Betula platyphylla, Populus davidiana, Juglans mandshurica, Fraxinus mandshurica, Phellodendron amurense.* There are many communities, such as *Quercus mongolica* forest, *Betula platyphylla* forest, *Populus davidian* forest, *Fraxinus mandshurica* forest, *Phellodendron amurense* forest, meadow and wetland.

This area has has the temperate zone monsoonal climate, with an annual average temperature of 2.6 °C (6 years), the lowest temperature of -31.9 °C in January and the highest temperature of 26.1 °C in July. We consider the factor of average temperature in a day as the standard to determine the length of a season. The summer period is one month, spring and fall is four months, and winter is 7 months long. Annual average precipitation is 723.8 mm, and about 54% occurs in July and August. Annual evaporation is 1093.3 mm. The frost-free period is 120-140 days. Annual average sun-shining hours are 2471.3 h.. The typical mountain earth is dark brown forest soil. There are other types of soil including albic soil, meadow soil and mire soil.

Research method

In order to clarify the disturbance of Mao'ershan forest landscape structure and distribution, the landscape patches of Mao'ershan forest were classified and the distribution plot of landscape patch was drawn. The index of patch shape and the fragment index of forest habitat (including the fragment index of forest patch amount and the fragment index of forest hatch shape) were selected as indicators to analyze the Mao'ershan forest landscape pattern.

Patch classification

The ready landscape patch distribution plot referred to forest type map (1:10000) which was drawn by combining aerial photographs in 1999 and ground investigation, topography map drawn in 1993 (1:10000) and soil utilization map in 1999 (1:10000). According to soil utilizing status and management goals, 2-grade classification was adopted to truly reflect the landscape characters.

First grade: According to the soil utilizing status, patches are classified into forestland and non-forestland. Forestland is the region of vegetation covering degree≥0.4 in arboreal layer. Non-forestland is the region of vegetation covering degree<0.4 in arboreal layer including the land not for forestry objective.

Second grade: Based on the first grade, adding patch appearance, patch occurrence and origination and soil utilizing status, the patches are further classified into Korean pine plantation, larch plantation, *Mongolica* Litv plantation, broad-leaved and conifer mixed plantation, broad-leaved and conifer forest, hardwood broad-leaved forest, softwood broad-leaved forest, nursery, wetland, paddy field, cropland, badland, deforested land and wasteland.

Patch shape index

The patch shape index is usually expressed by using the ratio of patch perimeter to circle perimeter in the equal area.

$$Di = Pi / 2\sqrt{\pi Ai} \quad (1)$$

where, P_i is patch perimeters, A_i is patch area, D_i is patch shape index. These indices usually express the developed degree of landscape patch. The circle- patch ratio is one. The higher D_i, the more developed the patch border (Li *et al* 1992; wu *et al* 2000).

Habitat fragment index

Habitat fragmentation is an important character of extant landscape. The correlation between habitat fragmentation and nature conservation is significant. Many severe danger species need great natural region to maintain their living. With the reducing of landscape fragmentation and patch area, the range of favoring survival for creature is decreasing, which will influence the species reproduction, dispersal, migration and conservation. Furthermore, habitat fragmentation is an important element of landscape heterogeneity. Landscape fragmentation has some characters as follows: with the landscape patch amount increasing, the patch area decreases, patch shape becomes more irregular, and the area of landscape interior habitat decreases. As the material, energy and species intercourse, the forest landscape corridor is cut off. The landscape patches are separated from each other, thus, the forest islands has come into being. Li (1992) suggested that the different component of habitat fragmentation should be described by the different fragment index. The habit fragment index is described as the habit fragment degree in a landscape under the conditions of given time and quality. The extent of habit fragment index is from 0 to 1, which represents from no habit fragmentation to completely fragmentized (Fu *et al* 2001).

Fragmentation index of landscape patch amount

In order to find out the fragmentizing degree of landscape patch amount in Mao'ershan forest from different scaling, two fragment indices of landscape patch amount were adopted. The equation is follows:

$$F_{N1} = (N_p - 1) / N_c \quad (2)$$

$$F_{N2} = M_{PS} (N_f - 1) / N_c \quad (3)$$

where, F_{N1} and F_{N2}, F_{N1} is the fragment index of landscape patch amount in the whole region, F_{N2} is the fragment index of patch amount about each landscape. N_c is the grid amount included in the pane of landscape datum matrix, N_p is the total amount of patch in a landscape, M_{PS} is the mean area of patches which belong to the same type in a landscape (grid amount in a pane as unit), N_f is the total patch amount in all landscapes (Li *et al.* 1992; wu *et al* 2000).

In the study, the Equation (2) and (3) were reconstructed. N_c is the ratio of the least patch area to total area, namely, the least patch area as the grid size. This method can decrease the data change caused by different grid scaling, and the index becomes more stable in a classification system. M_{PS} is the least patch area amount as unit. In our calculation, the smallest patch was taken as square (Li *et al.* 2004).

Fragment index of landscape patch shape

The correlation between the fragment index of landscape patch shape and the landscape patch area is obvious. So, there are two fragment indices. One is the average shape fragment index of patch (F_{S1}); the other is the average shape fragment index of weighted area-F_{S2}. When the two indices are high, the patch fragmentation degree will be intense.

$$F_{S1} = 1 - 1/M_{SI} \quad (4)$$

$$F_{S2}=1—1/A_{SI} \quad (5)$$

$$MSI=\sum_{i=1}^{m} SI(i)/N \quad (6)$$

$$ASI=\sum_{i=1}^{m} A(i)SI(i)/A \quad (7)$$

$$SI(i)=P(i)/\left[4\sqrt{A(i)}\right] \quad (8)$$

$$A=\sum_{i=1}^{m} A(i) \quad (9)$$

where M_{SI} is the average shape index of landscape patch; A_{SI} is the average shape index by weighting area; $S_I(i)$ is the shape index of landscape patch i; $P(i)$ is the perimeter of landscape patch i; $A(i)$ is the area of landscape patch i; A-the landscape patch area. Note: $S_I(i)$ is a shape index taken square as standard, namely, the patch shape index of square is 1, the patch shape index of other shape is >1 (Li *et al.* 1992; Wu *et al.* 2000).

Results and analysis

Patch shape index analysis

The landscape patch shape index of Mao'ershan forest was calculated by using Equation (1). Fig. 1 shows that the patch average shape indices of natural secondary forest are higher. The reason is that some pioneering tree species in natural secondary forest have more adaptability, distribution extent is more extensive, and their patch shapes are more irregular. The pioneering community characters of softwood broad-leaved forest are most obvious; their shape indices are the highest. The coniferous-broadleaved forests based on the valuable broad-leaved tree species were cultured by artificially regenerated conifer. The formative process of plantation patch coexists with the patulous process of the natural forest patch. Then the different proportion mixed forest, which caused the patch shape irregular will be formed. Accordingly, the shape indices are higher. Plantation shape is more regular than that of natural forest when it is planted. Therefore, average patch shape index of plantation is second bigger. As the pockety farm, the shape index becomes higher. In all plantations, larch adaptability is higher, its area is bigger, and its shape types are diverse. Thus, larch shape index is bigger. Nursery, cropland, paddy field and deforested land belong to artificial patches. Their shapes are more regular such as nearly square, circle *etc.* So, their shape indices are smaller. Wasteland and wetland are scattered away, their disturbed degree is lower and their shape indices are higher.

Landscape fragmentation analysis

Fragment exponential analysis of landscape patch amount

Utilizing Equation (2) and (3), the fragment exponent of Mao'ershan forest patch amount was calculated. The value of F_{N1} and F_{N2} is limited in [0,1]. O represents no habit fragmentation and 1 represents all landscapes completely fragmentized. When the landscape total area (263.6582 km^2) divided by least patch area (0.000397km^2), Nc=664580.1 was drawn (The landscape total area and least patch area were drawn from the Mao'ershan forest landscape distribution plot by using ARC/INFO). F_{N1} is 0.004776. F_{N2}, namely the fragment index of patch amount in each landscape, was listed in the Fig. 2. The result of Fig. 2 reveals that in all natural secondary forests, the fragment indices of patch amounts in softwood broad-leaved forests are highest. The pioneering community characters of softwood broad-leaved forest are most obvious. Softwood broad-leaved forest forms scattered small patches easily, and patch spatial expansibility is more intensive, which leads to bigger patch amount, smaller size, and the highest fragment index of patch amount. In all plantations, the amount fragment index of larch plantation is highest; while the larch plantation index is smallest. The site conditions have less limitation to larch, so larch has extensive distributed extent and its size is smaller. The patch amount fragment indices of nursery, paddy field, wasteland and deforested land are smaller than those of other lands. That is because bigger patch are constructed during the cutting and reconstructing progresses. On all accounts, the patch amount fragment indices of woodland are bigger than that of non-woodland. One way is the property of tree species; the other way is that the forest management is unreasonable, especially, in the softwood broad-leaved forest, hardwood broad-leaved forest, Korean pine plantation and larch plantation. With the increasing human disturbance and the relentlessly cut of forest, the forest landscape was divided into many small patches and the integrity of environment was destroyed, and the interior habit was lessened, the corridor was cut off. The species and material currencies were affected. The increasing of patch amount affects the fragment index of patch amount strongly. The more the patch amount, the higher the fragment-index of patch amount. Therefore, the results of fragment index of patch amount are taken as a reference in evaluating the fragmentizing degree only, but not as an important or single index, and other results arrived from fragment index should be considered.

Fragmentation index analysis of patch shape

When the 2 kinds of fragment indices of patch shape in Equation (4) and (5) were larger, the degree of patch fragmentizing is high. Equation (4) and (5) are taken to calculate the fragment index of patch shape in Mao'ershan forest, and the fragment indices of patch shape of Mao'ershan forest are F_{S1} (0.899) and F_{S2} (0.938). The fragment indices of patch shape are shown in Fig. 3. The results of Fig. 3 and Fig. 1 indicate that the fragment index of patch shape has the same results as the shape index of patch shape. That is to say, in the natural forest, the landscape with higher fragment index of patch shape is softwood board-leaved forest. The phenomenon attributes to human disturbance and softwood board-leaved forest property. The softwood board-leaved forest extension is wider; in addition to the relentlessly cut the residual patches become more complex and irregular. In the plantations, the different management results in the different fragment indices. The mixed conifer plantation's fragment index of patch shape is lower, because the mixed conifer plantation has much more requirement of site conditions. They have been planted in the favorite mid-slope and lower-slope. Thus, their shape is more regular and their shape fragment indices are lower. Nursery, cropland and deforested land belong to artificial landscapes. Their shapes are more regular and their shape fragment indices are smaller. Wasteland and wetland with less human disturbance are limited by topography and site conditions. Their shapes are more irregular, and their fragment indices of patch shape are higher.

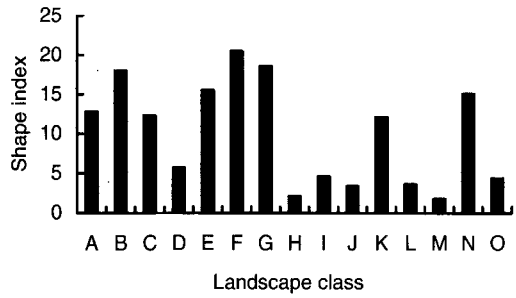

Fig. 1 Shape index analysis of Mao'ershan forests

Notes: A--Korean pine plantation. B--Larch plantation. C--Pinus sylvestric var. mongolica plantation. D--Conifer mixed plantation. E--Hardwood broad-leaved forest. F--Softwood broad-leaved forest. G-Conifer and broad-leaved mixed forest. H--Nursery. I--Cropland. J--Paddy field. K--Wasteland. L--Deforested woodland. M--Wasteland befitting for forest. N--Wetland. O--Other lands. Same for Fig 2 and 3

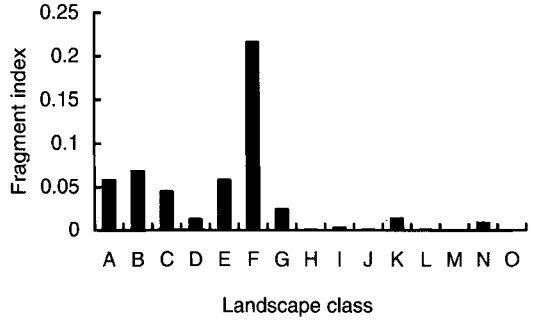

Fig. 2 Fragment index of patch amount in Mao'ershan forestes (F_{N2})

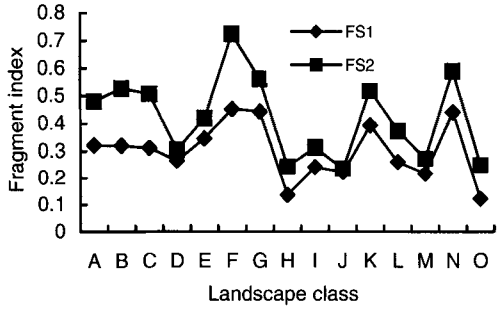

Fig. 3 The fragment index for landscape shape of Mao'ershan forests

Conclusions and discussion

Because of less human disturbance and more complexity, the shape index of natural forest is higher than that of plantation. The artificial landscapes, such as nursery, cropland and deforested land, have more regular shapes and smaller shape indices. Because of less human disturbance and complex shape, the shape indices and fragment indices of natural landscape patch shape are higher. Natural forest fragment indices of patch amount are bigger than that of plantation and non-woodland. Softwood broad-leaved forest fragment indices of patch amount are largest.

Combining the essential of fragment index of patch amount with the results of other fragment indices, the increasing of patch amount has much effect on fragment index of patch amount. So the fragment index of patch amount cannot be taken as a sole index to evaluate the landscape fragmentation.

Landscape fragmentation strongly depends on the tree ecological property (especially in dispersal ability, expandability and site adaptability) and the disturbed degree. According to the increasing human disturbance, the landscape fragment indices of patch amount increase. The fragment index of patch shape has complex relationship with human disturbance, mainly express in two aspects. One is negative correlation especially in the landscape strongly related to human activity, such as nursery, cropland and deforested woodland; the other is positive correlation especially in the natural and less disturbed landscape, such as forest landscape patch.

Due to intensive disturbance of human, the degree of the fragmentation for Mao'ershan forest landscape was heightened. A majority of forest areas has changed into cross band along with the fragmentation of forest landscape. This process has impacted on the forest Aves mammalian. The habitat for forest animal disappeared because the forest fragmentation. These creature would be replaced by those who lived in the forest edge or clearing. The predators formerly lived in the interior of forest decreased, while the adaptability predators increased. On the one hand, because of the increasing of forest fringe and cross-band area, the critical species increase, which is propitious to the conservation of biodiversity. On the other hand, the amount of creature, which need larger forest habitat to sustain their population developing, has decreased, because of the reduced inner environment, the severed of corridor and species intercommunion.

Therefore, the management of Mao'ershan forest should be strengthened, especially in the aspect of the management of natural landscapes, such as natural forest and wetland, etc. The sustainable utilization of resources and the biodiversity maintenance can be done. From now on, the rational and moderate utilization of resources should be done from the eye of landscape in developing economy.

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